University of Southern Queensland

Identifying strategies to improve the water productivity of permanent raised beds

A dissertation submitted by

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FOR THE AWARD OF

DOCTOR OF PHILOSOPHY

2013

ABSTRACT

Permanent raised bed (PRB) farming systems combine several elements (e.g. reduced tillage, controlled traffic, stubble retention) of conservation agriculture. PRB systems have recently been introduced into irrigated areas but there is a lack of information on the agronomic and irrigation performance of these systems under these conditions. Three years of field research into the performance of irrigated PRBs was conducted in south east Queensland, Australia and north west Pakistan. These studies benchmarked the irrigation performance of variously sized PRB systems and explored the impact of bed renovation method (no tillage (NT), shallow cultivation (SC) and blade ploughing (BP)) on soil hydro-physical properties (bulk density, soil moisture storage, infiltration), irrigation performance, crop yield and input water productivity (*WP*). Irrigation management strategies to improve lateral infiltration and irrigation performance were also investigated.

The initial benchmarking study was conducted on two farms with clayey Vertisol (Australia) and three farms with sandy clay loam, Alfisol, (Pakistan) soils. The results showed low irrigation performance with excessive deep drainage potential. The irrigation application efficiency (*Ea*) on the clayey Vertisol and sandy clay loam was as low as 68% and 50%, requirement efficiency (*Er*) 96% and 77% and distribution uniformity (*DU)* 86% and 66%, respectively. However, the majority of the narrow beds (66 cm furrow spacing) were over-irrigated on the sandy clay loam while the wide beds (132 cm furrow spacing) were under-irrigated. Inappropriate renovation and bed furrow dimensions, sub-optimal irrigation management and poor lateral infiltration were the main factors likely to affect *WP* of irrigated PRBs.

The evaluation of bed renovation methods found that BP on the clayey Vertisol reduced (~6%) the average seasonal bulk density of the surface 0-30 cm compared to the NT treatment. BP was found to produce higher lateral infiltration into the beds than either NT or SC. Freshly applied BP and SC produced a higher (~23%) cumulative infiltration than NT but the effect was transient and was not significant in the following season when the PRB renovation treatments were not freshly applied. The SC beds slump more than the BP and NT beds. The soil water content in the beds indicated that there was increased water storage associated with BP.

PRB renovation (i.e. SC or BP) was found to reduce irrigation performance on the clayey Vertisol when the irrigation was farmer managed. The volume of irrigation water applied to the fresh SC and BP treatments increased by up 13% and 55%, and *Ea* was reduced by up to 9% and 29% respectively, compared with NT during the 2010 wheat and 2011 corn seasons. NT produced a higher wheat yield and *WP*, but the lower wheat yield in the cultivated treatments was associated with poor crop establishment from a rough soil surface and inadequate seeder performance in this season. In the subsequent seasons, there was no significant difference in either the crop yields or *WP* between the bed renovation treatments.

Field trials investigating the effect of bed renovation on infiltration were conducted on both soils. Significant differences in the amount of water infiltrated and stored in the bed shoulder and bed middle were found for periods of wetting consistent with normal irrigation practices. This suggests that the general assumption of uniform soil moisture distribution across the beds is not valid for wide PRB systems. The three different renovation methods also significantly affected lateral infiltration, suggesting tillage may be used as a management tool to improve bed wetting in low infiltration soils and subsided beds.

Infiltration and soil-water movement were simulated using Hydrus 2D. The simulations were found to be well correlated with the measured field data and an evaluation for the three PRB renovation methods confirmed that NT had the slowest, and BP the fastest, potential to wet the bed middle of the wide PRBs. Increasing the furrow water head from 4 cm to furrow full of water was also shown to reduce wetting time by more than 30%.

Lateral infiltration was poor in the sandy clay loam. The shortest wetting time (~15 hrs) required to wet the bed middle of a 132 cm wide bed to field capacity occurred when furrow full water head was applied to the BP treated bed. However, even this period of wetting may be difficult to achieve using current irrigation practices in Pakistan. The graphical model outputs developed can be used in developing guidelines to optimise bed width and irrigation management to ensure adequate lateral infiltration with different PRB renovation methods.

Strategies to optimise irrigation management and field design while ensuring adequate lateral infiltration into the bed middle were evaluated using the surface irrigation model SIRMOD. Optimising the inflow rate (*Q*) and the time to cut-off (*Tco*) for the particular field length was found to produce up to a 38% irrigation water saving compared with existing practices. However, the majority of the wide beds on the sandy clay loam required higher inflow volumes than currently applied, which increased *Er* but reduced *Ea*. Optimising furrow length indicated a further improvement in irrigation performance. Similarly, *Q* and *Tco* optimisation together showed up to 35% irrigation water saving and up to 33% improved *Ea* for the most sub-optimally managed BP treatment. Decreased furrow length improved irrigation performance for freshly renovated PRB, while irrigation performance of settled bed furrows tended to increase with increased furrow length. Relating optimum *Tco* to water advance to furrow tail end (*Ta*) was sensitive to furrow length, *Q* and soil infiltration functions. The decision support guidelines developed were helpful in improving existing irrigation performance under both soil conditions.

This research has shown that the existing irrigation performance of PRBs is often low and highly variable. A key constraint is the potential for poor lateral infiltration into the beds and inadequate wetting to the centre of wide beds. However, this work has also highlighted that the adoption of appropriate bed renovation methods (particularly BP) and irrigation management practices (e.g. *Q* and *Tco*) can substantially improve irrigation performance and input *WP*. Although the applicability of the specific decision support tools developed is restricted to the soil types and field conditions encountered, the general understanding and insight into the basic principles of performance optimisation and for agronomic and irrigation interactions is expected to be beneficial in refining understanding and the promotion of sustainable crop production under a wider range of environmental conditions.

CERTIFICATION OF DISSERTATION

I certify that the ideas, designs, experimental work, software, results, analyses and conclusions presented in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Signature of candidate Date

Endorsement:

Professor Steven Raine (Principal supervisor) Date

Dr Allen David McHugh (Associate supervisor) Date

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and appreciations to a number of people who have helped me during this research. I am grateful to Professor Steven Raine for his timely supervision, guidance, academic, technical and personal support. I greatly admire his capabilities of quick assessment, which greatly benefited me in solving multiple technical, writing and field related issues. I particularly acknowledge the major assistance provided to me by Dr Allen (Jack) McHugh in technical support and in improving my presentation and writing capabilities. Never once did he turn me away in an unscheduled meeting when I needed help, and I know this was at the expense of his own workload. I am extremely thankful to Mr Greg Hamilton, who not only supported me in getting the PhD fellowship but continued to guide me throughout the duration of this work. I cannot forget his personal contribution and support in my career development.

I acknowledge the support of the Australian Centre for International Agriculture Research (ACIAR) for providing me a fellowship, the National Centre for Engineering and Agriculture (NCEA) at the University of Southern Queensland (USQ), and its friendly staff for providing me the necessary equipment, field conveyance and technical support. I acknowledge the Pakistan Agricultural Research Council (PARC) and my colleagues for their cooperation and all possible support.

I greatly appreciate my collaborative farmers, especially Mr David House (Cambooya, Australia) and Mr Feroz Shah (Mardan, north west Pakistan) for providing me field access and support in establishing the field trials. Many thanks to Dr Jochen Eberhard, Dr Malcolm Gillies, Dr Simon White, and Professor Shah Jahan Khan for their guidance, discussion, technical and statistical consultation support.

I wish to express my humble obligation to my mother, wife, two sons and one daughter for their love, prayers, support, motivation and patience. The physical support in crop sample handling, moral support and encouragement from my wife during the hard days of lengthy field work was always crucial in motivating me to accomplish this research study.

PUBLICATIONS ARISING FROM THIS RESEARCH

Akbar, G, Hamilton, GJ & Raine SR 2010, 'Permanent raised bed configurations and renovation methods affect crop performance', In: *19th World Congress on Soil Science*, August 2010, Brisbane Australia.

Akbar, G, McHugh, AD, Raine, SR & Hamilton GJ 2011, 'A preliminary evaluation of furrow inflow rate and cut-off time on the performance of smallholder raised bed farming systems', In: *World Congress on Conservation Agriculture,* September 2011, Brisbane Australia.

Akbar, G, Raine, SR, McHugh, AD & Hamilton GJ 2011, 'A preliminary evaluation of irrigation performance and in season changes under permanent raised beds on Vertisol in Queensland, Australia', In: *World Congress on Conservation Agriculture*, September 2011, Brisbane Australia.

Akbar, G, Raine, SR, McHugh, AD & Hamilton, GJ 2012, 'A soil management technique to enhance lateral infiltration (subbing) in permanent raised bed', In: *ICID Irrigation Australia Conference and Exhibition*, Adelaide Convention Centre, June 25-29, 2012, Adelaide Australia.

Akbar, G, Raine, SR, McHugh, AD & Hamilton, GJ 2012, ‘Impact of renovating permanent raised beds on water productivity under Vertisol’, In: *ICID Irrigation Australia Conference and Exhibition*, Adelaide Convention Centre, June 25-29, 2012, Adelaide Australia.

The following journal papers are in the final stages of review between the authors and are expected to be submitted in the near future:

Akbar, G, Raine, S, McHugh, AD & Hamilton, GJ 'Strategies to improve the irrigation performance of raised beds on small farms in north west Pakistan', will be submitted soon to *Water Resources Management* Journal (Springer).

Akbar, G, Raine, S, McHugh, AD & Hamilton GJ 'Impact on irrigation performance and productivity of permanent raised bed renovation methods on a Vertisol', will be submitted soon to *Crop and Pasture Science* Journal (CSIRO).

Akbar, G, Raine, S, McHugh, AD & Hamilton GJ "Modelling lateral infiltration under different renovation methods of permanent raised beds and furrow water heads in a Vertisol and a sandy clay loam', will be submitted to *Irrigation Science* (Springer).

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LIST OF ABBREVIATIONS

ACIAR	Australian Centre for International Agricultural Research
BD	bulk density
BP	blade ploughing
BW	bottom width of furrow
CA	conservation agriculture
CTF	control traffic farming
D	depth of furrow
DD	deep drainage losses
DU	distribution uniformity
Ea	application efficiency
Er	requirement efficiency
FC	field capacity
MW	middle width of furrow
NB	narrow bed (66 cm furrow spacing)
NCEA	National Centre for Engineering in Agriculture
NT	no tillage
PARC	Pakistan Agricultural Research Council
PRB	Permanent raised bed
Qld	Queensland
SC	shallow cultivation
SD	standard deviation
SM	soil moisture
SMD	soil moisture deficit
Ta	time of irrigation water advance to furrow tail end
Tco	time to cut-off
TW	top width of furrow
WB	wide bed (132 cm furrow spacing)
WP	wetted perimeter
WP	input water productivity

LIST OF SYMBOLS

A	cross sectional area of flow
a	Kostiakov infiltration exponent
D_f	diffusivity
f_o	steady state infiltration rate of the soil
g	acceleration due to gravity
I	infiltration rate
k	Kostiakov infiltration equation coefficient
Q	inflow rate
r	fitted parameter
S	sorptivity
S_f	frictional slope
S_o	furrow slope
v	flow velocity
y	furrow water head
Z	cumulative infiltration
Θ	volumetric soil moisture content
ρ_b	bulk density
ρ_s	particle density
σ_y	surface storage shape factor
σ_z	subsurface storage coefficient
F	scaling factor
φ	boltzman transform
Ψ	soil moisture potential